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FOR

ENGINEERING DEVELOPMENT OF ADVANCED COAL-FIRED
LOW-EMISSION BOILER SYSTEMS

SUBMITTED BY:

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EXECUTIVE SUMMARY

INTRODUCTION

The Pittsburgh Energy Technology center of the U.S. Department of Energy (DOE) has contracted with Combustion Engineering, Inc. (ABB CE) to perform work on the "Engineering Development of Advanced Coal-Fired Low-Emission Boiler Systems" Project and has authorized ABB CE to complete Phase I on a cost-reimbursable basis and Phases II and III on a cost-share basis.

The overall objective of the Project is the expedited commercialization of advanced coal-fired low-emission boiler systems. The specified primary objectives are:

	Preferred Performance	Minimum Performance
NO _x Emissions, lb/million Btu	0.1	0.2
*SO ₂ Emissions, lb/million Btu	0.1	0.2
Particulate Emissions, lb/million Btu	0.01	0.015
Net Plant (HHV) Efficiency, %	45	42

*3 lb S/million Btu in the coal

The specific secondary objectives are:

- Improved ash disposability.
- Reduced waste generation.
- Reduced air toxics emissions.

The final deliverables are a design data base that will allow future coal-fired power plants to meet the stated objectives and a preliminary design of a Commercial Generation Unit.

The work in Phase I covered a 24-month period and included system analysis, RD&T Plan formulation, component definition, and preliminary Commercial Generating Unit (CGU) design.

Phase II will cover a 24-month period and will include preliminary Proof-of-Concept Test Facility (POCTF) design and subsystem testing.

Phase III will cover a 6-month period and will produce a revised CGU design and a revised POCTF design, cost estimate and a test plan.

Phase IV, the final Phase, will cover a 36-month period and will include POCTF detailed design, construction, testing, and evaluation.

The project will be managed by ABB CE as the contractor and the work will be accomplished and/or guided by this contractor and the following team members.

- DOE Contracting Officer's Representative (COR)
- ABB Combustion Engineering Systems (ABB ES)
- ABB Environment Systems, Inc. (ABBES)
- Raytheon Engineers and Constructors, Inc. (RE&C)
- Dr. Janos Beér, MIT and Dr. Jon McGowan, U. of Mass.
- Association of Edison Illuminating Companies - Power Generation Committee (AEIC)
- Advanced Energy Systems Corporation (AES)
- Black Beauty Coal Company
- Electric Power Research Institute (EPRI)
- Illinois Clean Coal Institute (ICCI)
- Peridot Chemicals, Inc.
- Richmond Power & Light (RP&L)
- Southern Company Services, Inc. (SCS)

SUMMARY

The Project is under budget and generally on schedule. The current status is shown in the Milestone Schedule Status Report included as Appendix A. Task 7 - Component Development and Optimization and Task 11 - Subsystem Test Operation and evaluation are shown to be slightly behind schedule. Also, addition of Kalina technology may delay completion of Task 8. However, Phase II will be completed on schedule. All Plans were updated based on delaying the start of Phase III six months to October 1, 1996. A revised Statement of Work formalized the stricter performance targets previously agreed to.

The Project and plans for the POCTF were presented to the Richmond Power & Light Board of Directors. Technology transfer activities included delivering papers at two conferences, submitting paper abstracts for two other conferences and organizing a Technical Session for a conference.

Under Task 7 the 200 acfm CeraMem filter test rig was installed at Richmond Power & Light and testing commenced. Low-NO_x firing system work was essentially completed.

In Task 8 integrating and optimizing the performance and design of the boiler, turbine/generator and heat exchangers of the Kalina cycle is proceeding but it has required much more time than anticipated. Preliminary designs of this equipment are nearly complete. Plant design and licensing activities will restart in April.

The test designs and plan created in Task 9 were previously submitted and approved, although the plan for the 5,000 acfm CeraMem filter test will be updated following completion of the 200 acfm test.

Task 10 work is nearly complete. The test rig for the 5,000 acfm CeraMem test has been shipped to the fabricator's shop, inspected, cleaned and is being modified based on input from the 200 acfm testing.

Task 11 work on the CeraMem filter was delayed and is expected to be started during the next reporting period. The second series of combustion testing of the low-NO_x firing system was completed and the data is being analyzed. Early review indicates that 0.1 lb of NO_x/million Btu may be achievable with reasonable stoichiometry and carbon loss.

Plans for the next reporting period include: initiating the 5,000 acfm CeraMem filter test, continuing work on the POCTF preliminary design (with a Kalina cycle), and report writing.

TASK 1 - PROJECT PLANNING AND MANAGEMENT

The Project is under budget and generally on schedule. The current status is shown in the Milestone Schedule Status Report included as Appendix A. Task 7 - Component Development and Optimization is shown to be slightly behind schedule. Also, addition of Kalina technology may delay completion of Task 8. However, Phase II will be completed on schedule. All work in Task 1 and all Task 1 deliverables for the reporting period were completed on schedule. All quarterly reports and all monthly Status, Summary, Milestone Schedule Status, and Cost Management reports were submitted on schedule.

Contract Mods 015, 016 and 017 were received and accepted; 015 and 016 increased the DOE's funding obligation and 017 changed the starting date for Phase III from April 1, 1996 to October 1, 1996.

Based on starting Phase III on October 1, 1996, and on results of a top management review of objectives, the following Plans were updated.

- Management Plan
- Work Plan (Section V of the Management Plan)
- Milestone Schedule Plan
- Cost Plan
- QA/QC Plan

A revised Statement of Work (Revision 3) was received and accepted. This formalized the stricter performance targets of the Project as follows: (ABB unilaterally increased the efficiency target from 42% to 45%)

		<u>Preferred Performance</u>	<u>Minimum Performance</u>
SO ₂	lb/Million Btu*	0.1	0.2
Particulate	lb/Million Btu	0.01	0.015
NO _x	lb/Million Btu	0.1	0.2
Efficiency	(Net, HHV) %	45	42

*3 lb S/Million Btu in the coal

The ABB Team and the DOE-PETC presented the LEBS Project and the proposed plans for the POCTF to the Richmond Power & Light Board of Directors. The objective was to familiarize the Board with the objectives of the Project, the role of the DOE and each ABB Team member, the proposed POCTF design and the benefits to RP&L and its customers. The presentation was well received and a good dialogue with the Board ensued.

Technology transfer activities consisted of the following:

- A paper titled "Major Improvements in Pulverized Coal Plant Design" was presented at The 21st International Technical Conference on Coal Utilization & Fuel Systems.
- A paper titled "Advancements in Low NO_x Tangential Firing Systems" was presented at the Institute of Clean Air Companies - Forum '96.
- An abstract of a paper was submitted to the '96 International Joint Power Generation Conference (IJPGC).
- Plans were formed for a Technical Session at the '96 IJPGC titled "Systems Developed Under DOE's Combustion 2000 Program".
- An abstract of a paper was submitted for the Thirteenth Annual International Pittsburgh Coal Conference.

The first LEBS Contractor Performance Report was received and accepted. ABB received the highest rating in all categories.

TASK 7 - COMPONENT DEVELOPMENT AND OPTIMIZATION

SNO_x™ Hot Process

Following a negative response from Ohio Edison (who recently downsized their engineering staff) Richmond Power & Light (RP&L) offered their Whitewater Valley Unit 1 as host site for Task 7 work. The offer was accepted and a meeting was held at RP&L January 19 to discuss engineering issues with plant and erector contractor personnel. Purchase orders for erector and analytical subcontractors were let. Subsequently ABBES staff reductions and office relocation resulted in a project delay of approximately three weeks.

The following activities preceded operation of the test unit:

- Held meeting with subcontractors to finalize project schedule 7 Feb.
- Site installation of unit started weekend of 3 Feb with installation of boiler taps. Installation subcontractor on site 12 Feb.
- Test unit sited and assembled week of 16 Feb.
- Duct work installation completed. All fixed runs installed. Expansion joints and gate valves delivery delays were crucial to the project. Expansion joints were not received until 1 Mar (one week late of expected delivery date). Correct gate valves received 27 Feb (one week late of expected delivery). Secondary booster fan delivered 5 Mar. Inlet and outlet sampling runs were fabricated. Duct work insulation was held up because of these delays.
- Weather structure completed, and withstood several heavy thunderstorms.
- Installation of subsystem control complete. Control panels mounted in weather structure, and elements installed onto subsystem.. Elements wired to control panel.
- Installation of power supply. Electrical motor leads connected. Transformer moved and installed in weather structure. Progress was held up by late delivery of power supply cable.
- Unit was tested on air and was heated up.

The unit is on-line and running on flue gas during the day. The unit is on by-pass over night to maintain temperature. It had been operated for approximately 75 hours on flue gas at month's end. It is removing ash from the flue-gas and the pulse air system seems to be cleaning the filters. Initial gas sampling has been completed. Operation is stable.

The unit is operating at the following conditions:

- Filtration temperature - approx. 650 F.
- Filter Face Velocity - approx. 2.5 - 4.75 ft/min.
- Cleaning pulse duration - 300 milliseconds

- Pulse dwell - 15 minutes, complete cycle (diametric opposing solenoids fire on alternating 7.5 minute schedule).

Tubesheet differential pressure (sum of filter differential pressure and venturi differential pressure) is approximately 16-16.5 inches w.c. "clean". At the end of half-dwell time, tubesheet differential pressure increases approximately on-half to three-quarters inch w.c.

Target temperature of 775 F may not be achievable due to combination of factors:

- higher than expected heat loss from boiler pick-up,
- higher than expected heat loss from vessel body,
- laminar-turbulent flow ($Re=12,000-15,000$) in heater area resulting in less efficient heat transfer from heaters to flue gas,
- laminar-turbulent flow through vortex flow-meter, resulting in inability to run by-pass to maintain temperature during operation of filter without sacrificing flow measurement.

The temperature achieved to date (650 F) is well within the range required for catalytic NO_x reduction.

Low- NO_x Firing System

The overall objective is to develop an advanced firing system which reduces the NO_x emission levels leaving the furnace to 0.10 lb/MMBtu or lower while maintaining carbon in ash at 5% or less. Included in this scope is an integrated effort combining Computational Modeling, fundamental scale evaluation of firing system concepts performed in the Fundamental Scale Burner Facility (FSBF), characterization of the pulverizer system performance utilizing the Pulverizer Development Facility (PDF), and pilot scale testing of the firing system in the Boiler Simulation Facility (BSF).

Computational Modeling: Computational Fluid Dynamic (CFD) modeling has been used in the development and evaluation of low NO_x firing systems. In addition to vertical and horizontal staging, evaluations of various 2-corner coal, helical, and 2-corner close coupled overfire air (CCOFA) firing arrangements were evaluated. (As defined for this work, "vertical" staging is the biasing or non-uniform introduction of fuel and air from elevation to elevation within the windbox, *i.e.*, in the vertical direction. "Horizontal" staging is similar but the biasing is between corners, *i.e.*, in the horizontal direction. The "helical" configuration combines vertical and horizontal staging by alternating fuel and/or air nozzles in a given elevation of nozzles.) Results from each of these simulations were benchmarked against the TFS 2000™ firing arrangement to identify potential impacts of these firing system modifications on furnace aerodynamics and low emissions potential. The insights gained in this

modeling effort were used to screen potential firing system concepts and to better focus the pilot scale experimental testing, in Task 11.

In general, the modeling results indicated that many of the proposed firing arrangements were viable when applied to the BSF geometry, though visible differences in the gas flow, species and temperature distributions in the main windbox zone were predicted, when compared against the TFS 2000™ arrangement. One of the concerns which was identified as a result of these modifications was the impact on the furnace wall heat absorption patterns.

Predicted horizontal heat absorption profiles for the standard TFS 2000™ firing system, shown in Figure 7-1, were similar on each of the four walls. In contrast, the corresponding lateral heat flux profiles for the 2-corner firing arrangement, shown in Figure 7-2, indicate different heat absorption profiles for the front and back walls, compared to the side walls. These differences are due to the more elliptical shape of the fireball which was seen for the 2-corner firing, as compared to standard 4-corner firing systems. However, it was also noted that the predicted peak absorption rates of approximately 15% above the average were similar for each of these arrangements. Modeling results for the helical firing arrangement, Figure 7-3, indicated that the horizontal heat flux profiles were not much different from those for the TFS 2000™ firing system. The corresponding vertical heat flux profiles for each of these arrangements is presented in Figure 7-4. Again, it is noted that the TFS 2000™ and the helical firing arrangements are similar, with the 2-corner firing arrangement peak absorption occurring higher in the furnace.

As a result of these observations, the number of heat flux measurements made during the recently completed pilot scale combustion testing in the BSF was increased. These measurements help better assess the impacts of these firing systems on boiler performance.

Bench Scale Corrosion: During this reporting period, a 500 hour bench scale exposure test under heat transfer conditions was completed. The test specimens included bare metal and chromized T-11 materials. These samples were exposed in a reducing gas environment at about 1300°C in a Carbolite furnace. The surface temperature of the test specimens was controlled at 500°C by cooling. Metallographic analysis of the exposed specimens to measure the morphology and the wastage rate are currently being conducted. Results obtained from this analysis will be compared to those previously obtained from isothermal testing.

In addition, near wall gas species measurements were obtained during the second week of pilot scale combustion testing in the BSF, completed in January. Included in these measurements was total reduced sulfur (TRS) and CO, which have been previously related to corrosion potential. The objective of these measurements was to characterize the near wall gas composition in the lower furnace under low NO_x firing conditions. Testing was done at four firing conditions, each comprising the helical firing arrangement. Preliminary results from this testing indicate

that both TRS and CO increase as stoichiometry is lowered. Additionally, it was seen that the location of the SOFA influenced these species concentrations, with increases in concentration measured when the SOFA is located further away from the main burner zone. These preliminary results are presented in Table 7-1.

Table 7-1 Preliminary Results from BSF Near Wall Gas Species Mapping

Test Number	126	127	128	134
Separate Overfire Air	Lower Elev.	Lower Elev.	Lower Elev.	Middle Elev.
Main Burner Stoichiometry	0.83	0.64	0.52	0.65
Main Burner Zone				
TRS (ppm)	2.6	13	38	46.6
CO (%)	0.14	0.99	2.8	2.3
Between MBZ and SOFA C				
TRS (ppm)	3.7	44.3	8	461
CO (%)	1.1	2.9	0.5	5
Between SOFA C and B				
TRS (ppm)	1.7	39	21	280
CO (%)	0.17	1.5	1.1	3.9
Outlet				
TRS (ppm)	230	149	152	109
CO (%)	0.31	0.21	0.21	0.15

Coal Pulverization: The evaluation of classifier geometry vs. particle size was completed. Results from this testing support previous findings from the CFD work. Classifiers which CFD showed to give more uniform air velocity distribution across the vanes are the ones which provide superior performance. Additional testing was performed in the Classifier Test Facility (CTF). This testing confirmed that more uniform velocities across the vanes (according to CFD) results in finer separation and improved top size control.

The Pulverizer Development Facility (PDF) was used to provide the pulverized coal that was used during pilot scale combustion testing in the BSF (Task 11), performed in January.

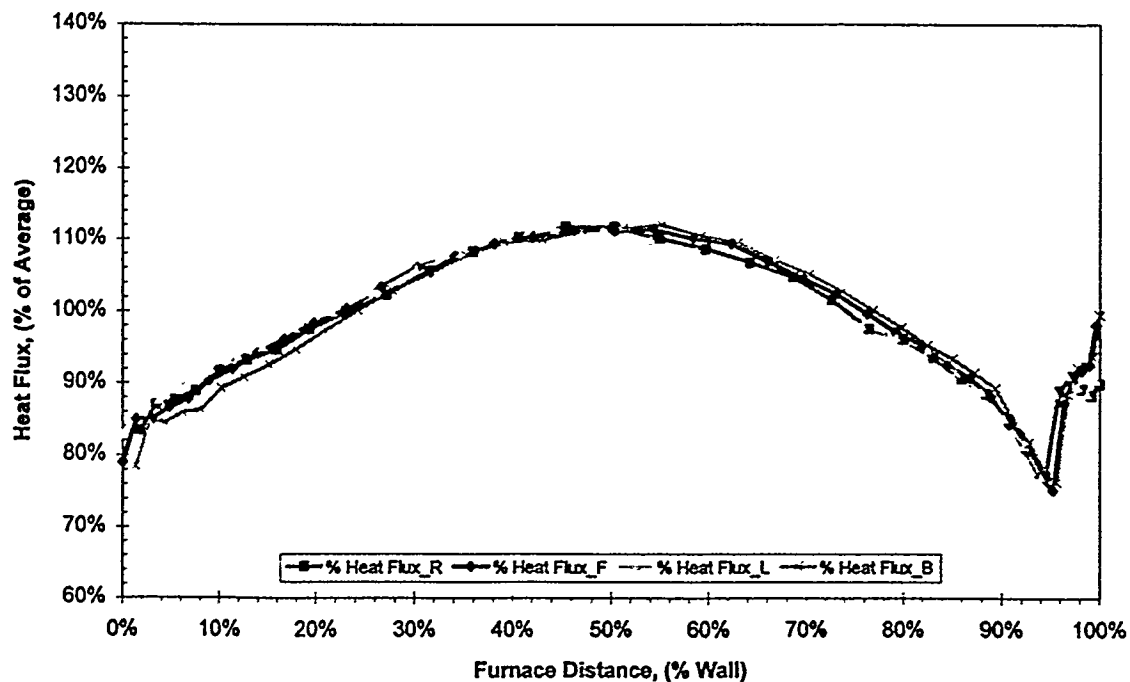


Figure 7-1 Horizontal Furnace Heat Flux Distribution
TFS 2000™ Arrangement

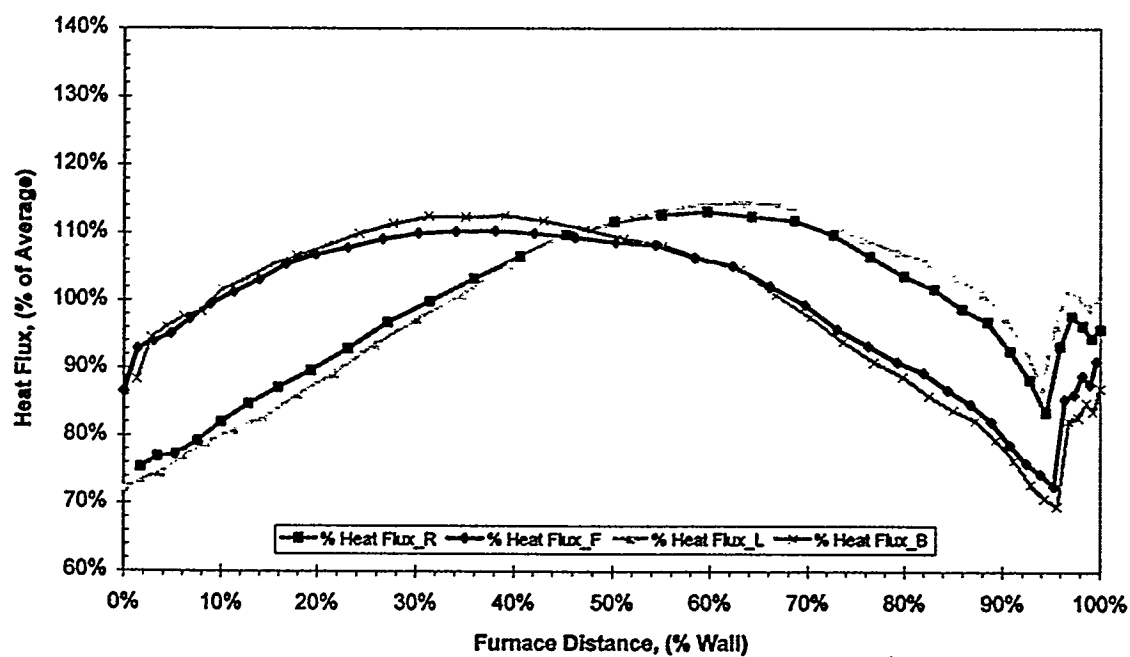


Figure 7-2 Horizontal Furnace Heat Flux
2 Corner Firing Arrangement

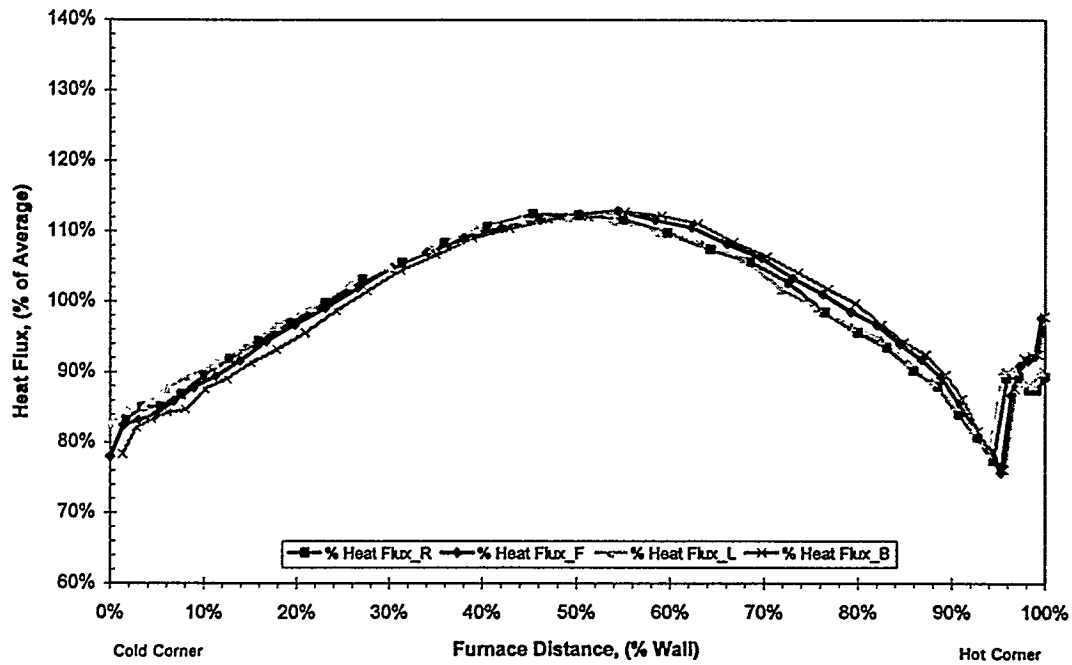


Figure 7-3 Horizontal Furnace Heat Flux Distribution
Helical Firing Arrangement

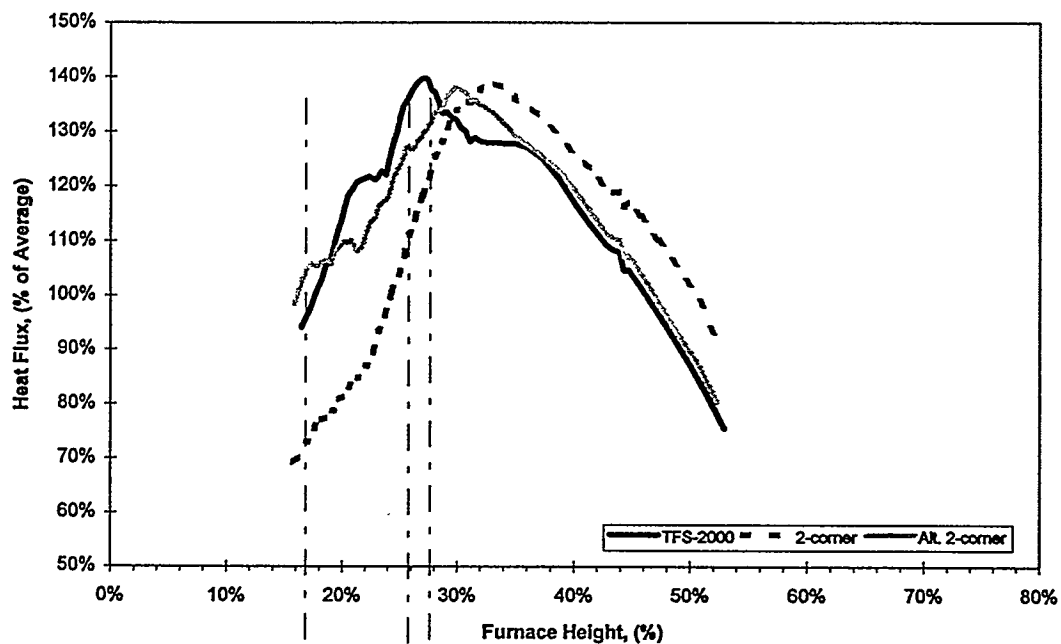


Figure 7-4 Furnace Vertical Heat Flux Distribution

TASK 8 - PRELIMINARY POC TEST FACILITY DESIGN

Site Selection

In October of 1994 ABB CE formally accepted the Richmond Power & Light (RP&L) offer of Whitewater Valley Unit No. 1 as the host site for the Proof-of-Concept Test Facility.

POCTF/RP&L Project

The proposed POCTF design is a repowering of RP&L Whitewater Valley Unit 1 (WV #1) with the LEBS technologies. Equipment between the coal bunker outlets and stack inlet along with the turbine/generator will be replaced. A listing of the major items of equipment is given in Figure 8-1. The overall project schedule is shown in Figure 8-2.

The key items of performance of the POCTF and a comparison to WV #1 are given in Figure 8-3. While these figures are preliminary, they reflect the substantial efficiency gain of the Kalina cycle and the dramatic reduction in emissions.

Kalina System Design

The cycle heat balance has been finalized to the extent possible at this time. The design is proceeding with a 2400 psi cycle at 1050 F superheater and 1050 F reheater conditions. Operations at the Canoga Park test facility have been and will continue to be beneficial in influencing the designs for the POCTF. Areas benefiting from testing at Canoga Park are materials acceptability, process control, and heat exchanger sizing. The balance of plant design will continue as major components are designed.

Boiler: Boiler design fluid conditions have been established for the furnace walls, superheater and reheater based on the Exergy heat balance. Surfacing calculations and arrangements of the boiler tubing, headers, and interconnecting piping have been generated and are in the process of refinement. The selection of materials will occur in the next reporting period. The air and gas areas of the boiler have been completed and designs are in progress for the major auxiliary equipment to support the boiler operation. The fuel handling and process equipment have been sized and arrangements are being prepared to properly interface with the existing equipment.

In parallel with the current boiler design effort, alternative arrangements and configurations are being investigated for optimizing reliability, ease of manufacture, cost impact, and operating conditions. Startup conditions, for example, have played a significant role in the arrangement, size, and configuration of the boiler.

Turbine: A two-case industrial turbine with gear reducer has been selected and configured to conform to the existing turbine pedestal at the RP&L site. The turbine/generator has a capacity of approximately 55 MW gross. The turbine materials selection investigations are continuing with several laboratory test conditions. The remaining turbine / generator interface information for balance of plant design is being developed for the next reporting period. The vapor flow to the high pressure turbine is approximately 640,000 lbs/hr with an approximate 302,000 lb/hr vapor flow for the low pressure stage.

Heat Exchangers: Sizing and configuration criteria are being reviewed and evaluated by a manufacturer using heat transfer correlations developed by Exergy. This continuing effort will optimize the design process and help obtain the most cost effective design. Layout of the exchangers and the configuration of the interconnecting piping will begin in May

Balance of Plant Design

The Raytheon preliminary design activities were on hold during the reporting period, awaiting the results of ABB's on-going integration/optimization of the Kalina power cycle and Kalina equipment designs.

Licensing

The NEPA Environmental Questionnaire for the POCTF project was revised to incorporate the Kalina cycle and to add another option for flue gas cleanup: an advanced dry scrubbing process. During the reporting period a draft of the revisions was prepared by Raytheon for ABB review and finalization.

Further work on the PSD permit application is on hold, pending potential revisions in the process design. Application forms for the state construction permit were obtained from IDEM, and the application completed and readied for RP&L signature. Further distribution is on hold, pending potential revisions in the process design.

Figure 8-1 - **POCTF/RP&L Project Scope**

Remove

- Boiler and Auxiliaries, Piping.
- Combustion Air and Flue Gas Systems.
- Turbine-Generator and Auxiliaries.
- Condensate/Feedwater System.
- Boiler and Turbine Controls.
- Turbine Hall West Wall.
- Miscellaneous Electrical.

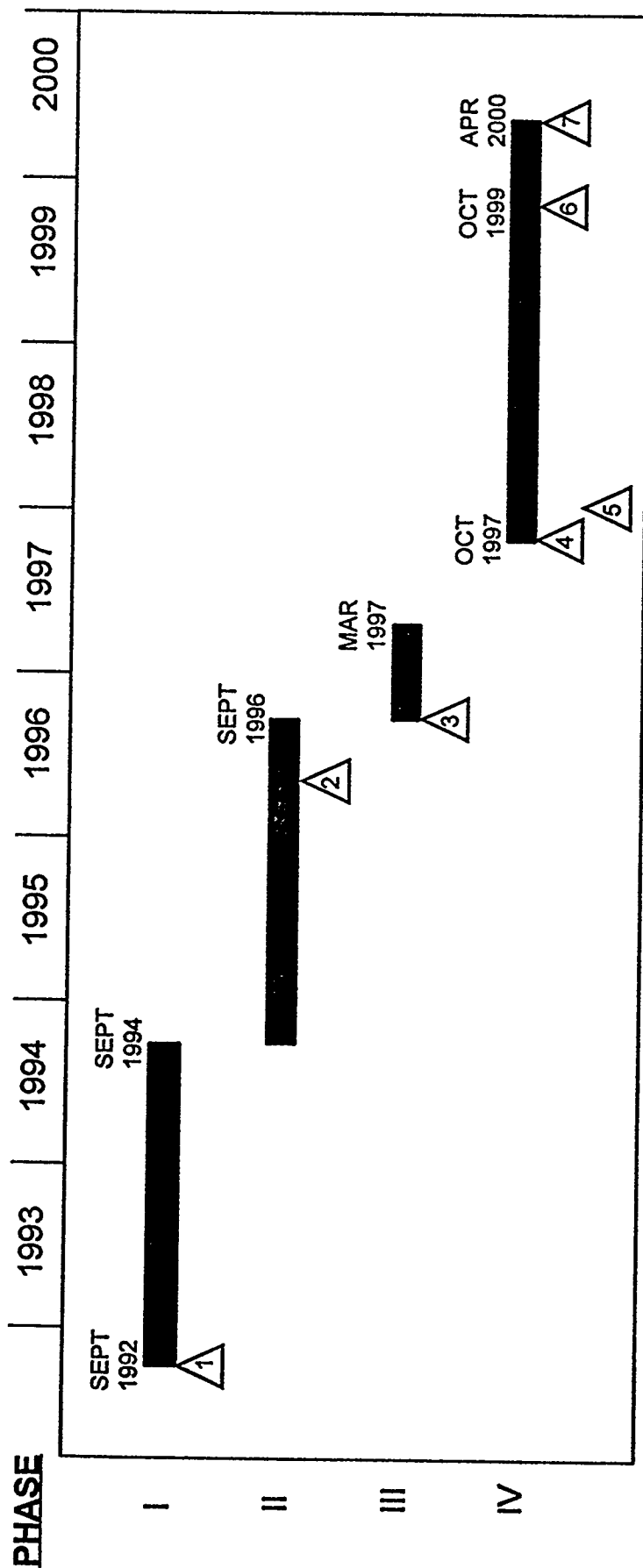
New

- Boiler and Auxiliaries, Piping.
- Combustion Air and Flue Gas Systems.
- Turbine-Generator and Auxiliaries.
- Condensate/"Feedwater" System.
- Boiler and Turbine Controls.
- Kalina Heat Exchangers.
- Building Extension for same.
- Ammonia Supply, Blowdown, Recovery.
- Air Soot Blowing System.
- Flue Gas Cleanup (SO₂ + Particulates).
- FGD Byproduct/Waste System.
- Miscellaneous Electrical.

Modify

- Cooling Tower.
- Boiler Supports.
- Turbine-Generator Supports.
- Flyash Handling.

Figure 8-2 - POCTF/RP&L Project Schedule



MILESTONES:

1. LEBS contract awarded.
2. Preliminary design submitted.
3. Start detailed design.
4. Final approvals.
5. Shutdown RP&L Whitewater Valley Unit 1.
6. Initial operation.
7. Project completion.

Figure 8-3 - **POCTF/RP&L Unit Performance**
(Preliminary)

THERMAL:		<u>WV#1</u>	<u>POCTF</u>
COAL FIRED	MMBtu/hr	400	440
COOLING TOWER LOAD	MMBtu/hr	216	215
GENERATOR OUTPUT	MW	35.6	54.6
AUXILIARY LOAD	MW	2.2	6.7
NET UNIT GENERATION	MW	33.4	47.9
NET UNIT HEAT RATE	Btu/kWh	12,000	9,186
<u>ENVIRONMENTAL:</u>			
SO ₂ *	lb/MMBtu	6.0/1.6	0.1-0.2
NO _x	lb/MMBtu	-/0.5	0.1-0.2
PARTICULATES	lb/MMBtu	0.19/0.19	0.01

* 3 lb S/MM Btu in the coal

TASK 9 - SUBSYSTEM TEST DESIGN AND PLAN

SNO_x Hot Process

The Subtask 9.2 Test Plan was submitted to DOE for their approval/comments. The Plan will be finalized by adding details generated in Task 7.

Low-NO_x Firing System

Completed in a previous reporting period.

TASK 10 - SUBSYSTEM TEST UNIT CONSTRUCTION

SNO_x Hot Process

The test rig for the 5,000 acfm test has been shipped to the fabricator's shop, inspected, cleaned and is being modified to operate under process conditions.

Low-NO_x Firing System

The Boiler Simulation Facility (BSF) was inspected and prepared for the second series of tests. No major modifications were required.

TASK 11 - SUBSYSTEM TEST OPERATION AND EVALUATION

SNO_x Hot Process

See Task 10 above.

Low-NO_x Firing System

Data analysis from the first week of combustion testing (October 1995) in the Boiler Simulation Facility (BSF) was performed. The objective of this testing was to evaluate enhancements to the existing NO_x control technologies for improved NO_x emissions performance, while providing the necessary information for supporting the design of the NO_x control subsystem for the LEBS Proof of Concept Test Facility (POCTF).

A summary of the results from testing various overfire air configurations with the test coal is given in Figure 11-1. As anticipated, the implementation of global air staging results in a significant reduction in furnace outlet NO_x emissions. NO_x emissions were reduced 75%, from a baseline of 0.52 pounds/ MMBtu to a low of 0.13 pounds/ MMBtu for an optimized TFS 2000™ firing system arrangement. As expected, carbon in flyash increased as the global staging increased, but remained below the performance limit of 5%.

Having benchmarked the effects of global staging on firing system performance, both vertical and horizontal staging techniques within the main firing zone were subsequently tested to evaluate their effects on NO_x performance. The objectives of this work were to confirm the results of prior main windbox vertical air staging work, and to further reduce outlet NO_x emissions from the previously demonstrated best level of 0.13 pounds/ MMBtu through the application of horizontal, and integrated vertical and horizontal (helical) main windbox staging techniques. As such, these methodologies were applied in concert with the optimized TFS 2000™ firing system, keeping the global stoichiometry history constant to allow meaningful comparisons.

Results from the vertical air staging, Figure 11-2, show that significant variation in NO_x emissions occur as main windbox vertical air staging is changed. In this testing, variations in this staging resulted in deviations in outlet NO_x of +/- 13% about the mean. This result confirms that the main windbox vertical stoichiometry history is an important contributor to overall NO_x formation, even with significant levels of global air staging. Overall, NO_x emissions increased when variations to the main windbox vertical stoichiometry build-up were applied to the previously optimized TFS 2000™ arrangement. This result is, however, expected since the optimized TFS 2000™ system incorporates the results of prior chemical kinetic and small scale combustion test vertical air staging work.

Next, horizontal staging techniques were evaluated. This testing included the biasing of air and/or fuel between each of the four corners, including variations of 2-corner firing arrangements. In general, horizontal staging techniques resulted in neutral to degraded NO_x emissions performance over that of the optimized TFS 2000™ firing system. A summary of these results are shown in Figure 11-3.

Finally, several configurations which applied integrated vertical and horizontal staging techniques as a means of "optimizing" the stoichiometry of combustion within the main windbox were evaluated. Integrated vertically and horizontally staged firing systems were extensively evaluated using CFD modeling prior to the BSF test. In contrast to their independent performance, Figure 11-4 shows that when suitably combined, an integrated vertical and horizontal staging strategy resulted in a small, but consistent improvement to the NO_x emissions performance of the optimized TFS 2000™ system. At a NO_x emission level of 0.11 pounds/MMBtu, the best integrated system (Integrated Config. 6 - helical) produced a greater than 10% reduction in NO_x over the previously optimized TFS 2000™ system. Carbon loss results (not shown) were also similar for the two firing systems.

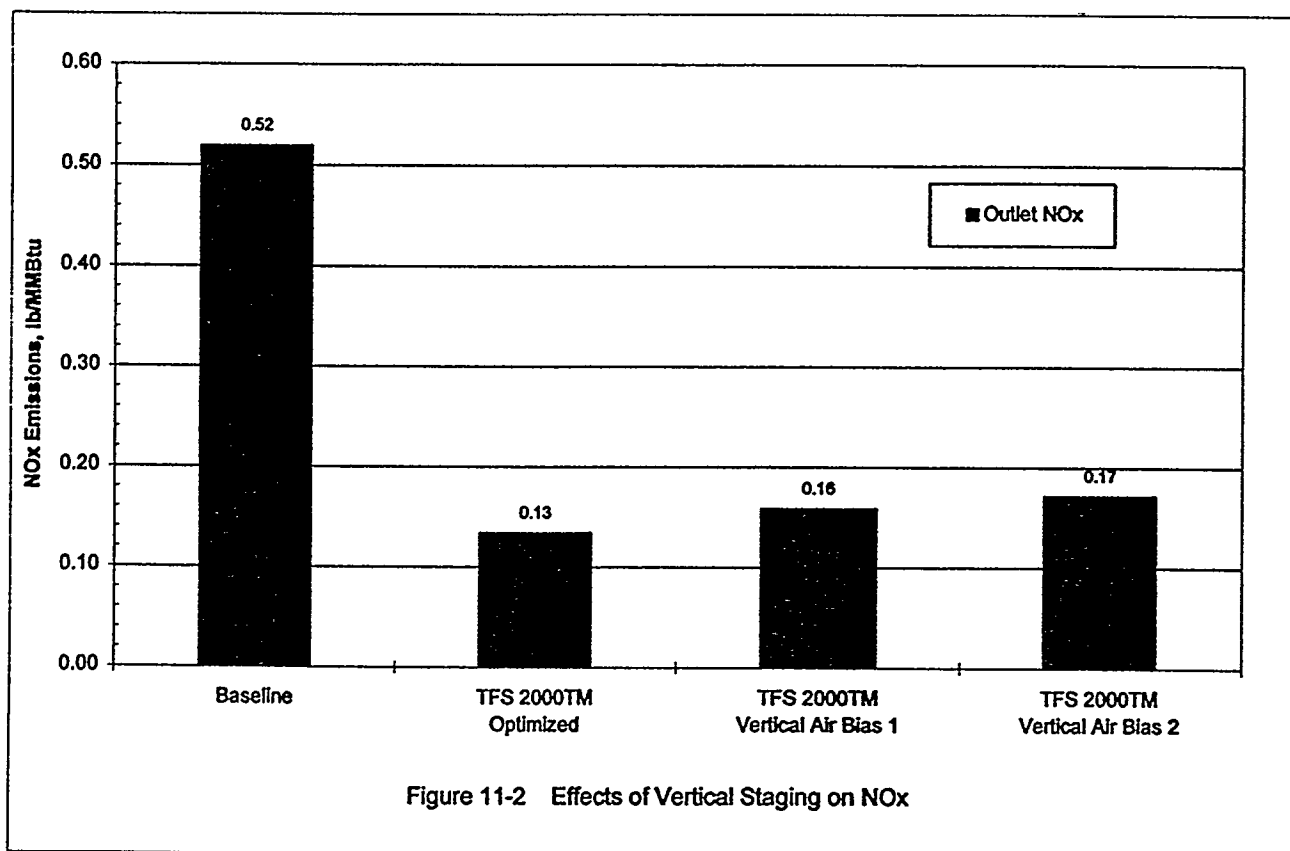
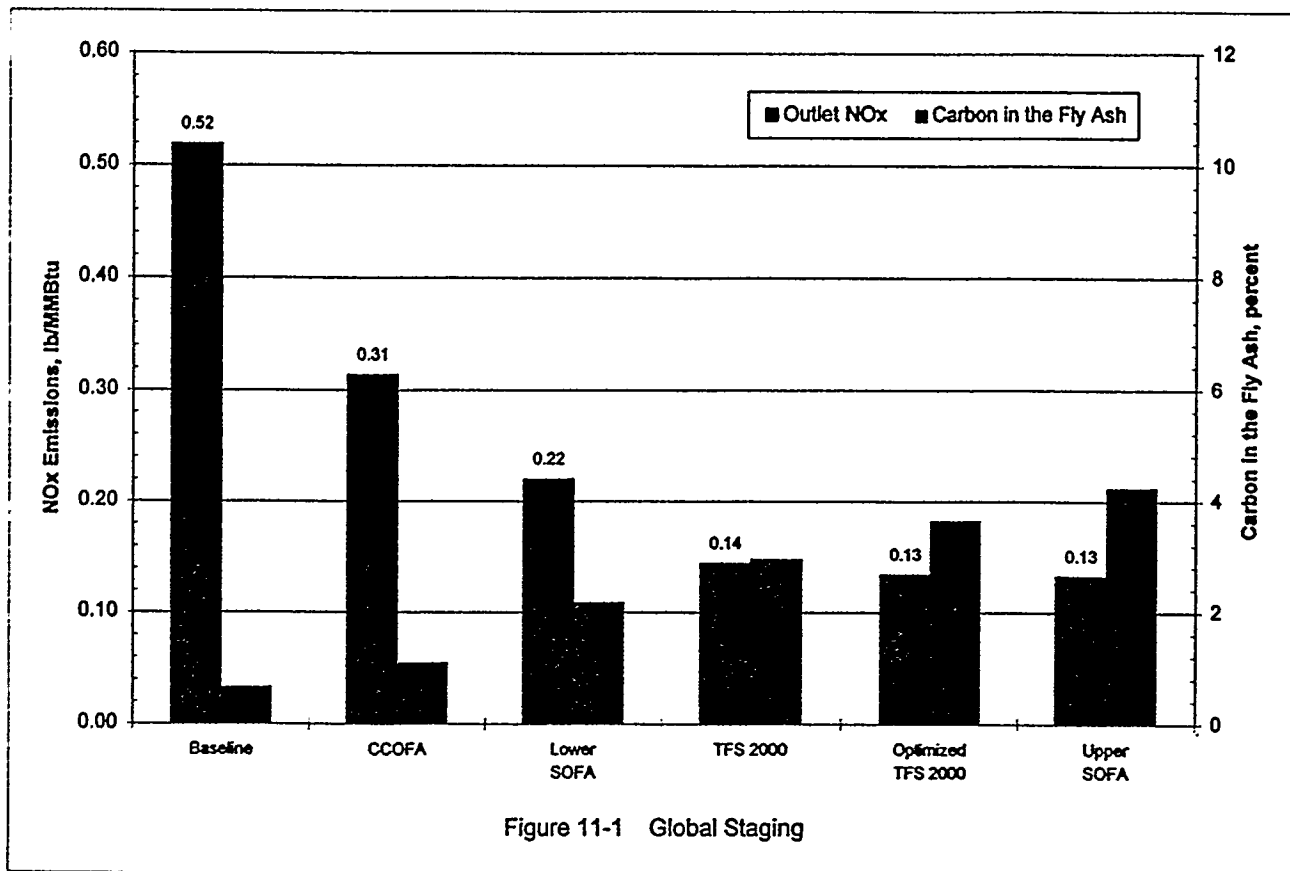
The second week of pilot combustion testing performed in the BSF was completed in January. This testing focused on the generation of a consistent design data set to be used in the scale-up of the NO_x control subsystem for the Commercial Generating Unit (CGU) and for the POCTF. This included detailed testing of firing system performance over a range of main burner stoichiometries, with various separated overfire air (SOFA) configurations. Both single and multiple levels of SOFA were utilized. Additionally, those advanced firing systems which demonstrated potential during the first week of combustion testing were re-tested over a greater range of furnace conditions. As was the case in the first test week, testing was performed using a 90% through 200 mesh grind of the Viking coal. This coal is a high volatile, high sulfur coal from Montgomery, Indiana which is currently fired at Richmond Power & Light, the proposed site of the POCTF.

During this second week of BSF testing, 48 combustion tests were performed. Data recorded during this testing was similar to that of the first test week. This included inlet air and fuel mass flows, furnace outlet emissions (O₂, CO, CO₂, SO₂, NO, and NO_x), and horizontal and vertical heat flux distributions. In addition, furnace outlet temperatures were measured, bottom ash samples collected, and iso-kinetic solids sampling in the furnace outlet duct was performed for selected test conditions.

Preliminary highlights from this second week of testing include:

- A test period low of 110 ppm NO_x (0.15 lb/ MMBtu) for several of the tested firing systems using only the middle elevation of SOFA was achieved. Carbon in the Fly Ash (CIFA) levels for these test conditions were typically <5%.
- A test period low of 115 ppm NO_x (0.16 lb/ MMBtu) for several of the tested firing systems using both the lower and middle elevations of SOFA was achieved with CIFA levels typically <5%.
- A test period low of 140 ppm NO_x (0.20 lb/ MMBtu) for several of the tested firing systems using only the lower elevation of SOFA was achieved with CIFA levels typically <5%.
- The generation of detailed NO_x versus stoichiometry curves for standard and advanced firing systems on the POCTF test coal were generated for each of the various SOFA arrangements previously mentioned.

It should be noted that the data reduction for this test period is nearly complete, with the analysis and final reporting currently under way. Details will be included in the report for the next reporting period and in the Phase II Report.



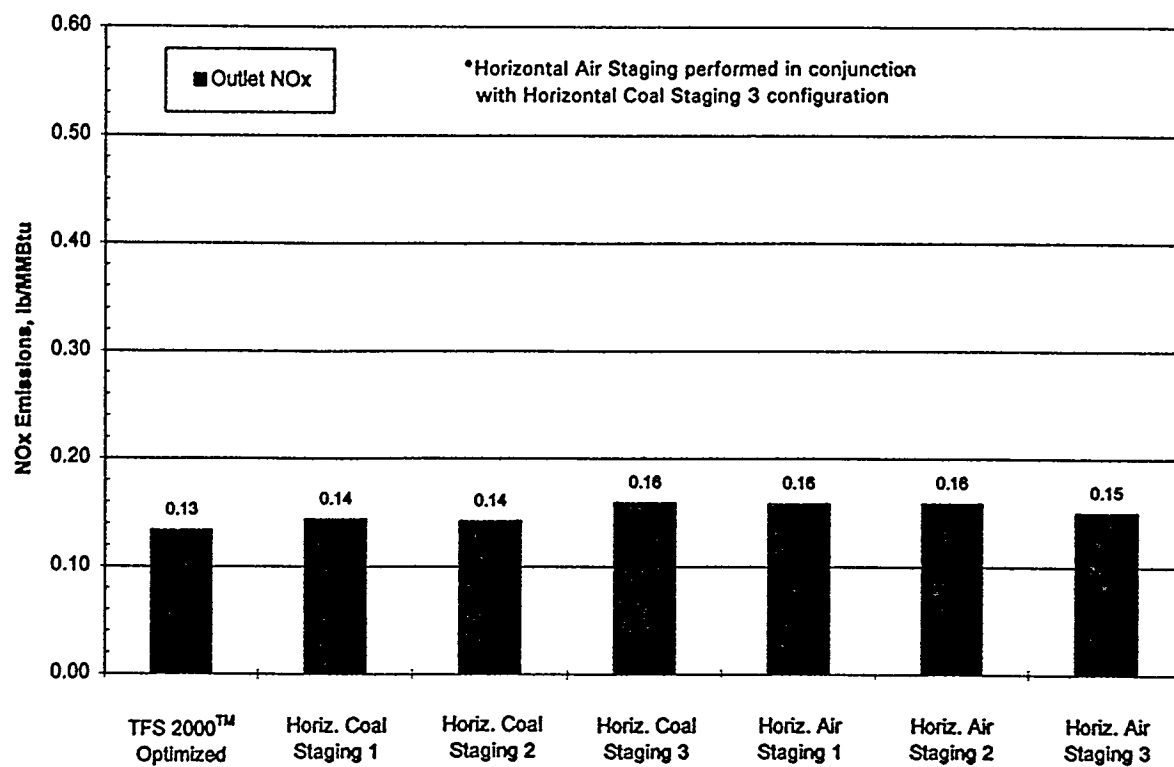


Figure 11-3 Effects of Horizontal Staging on NOx

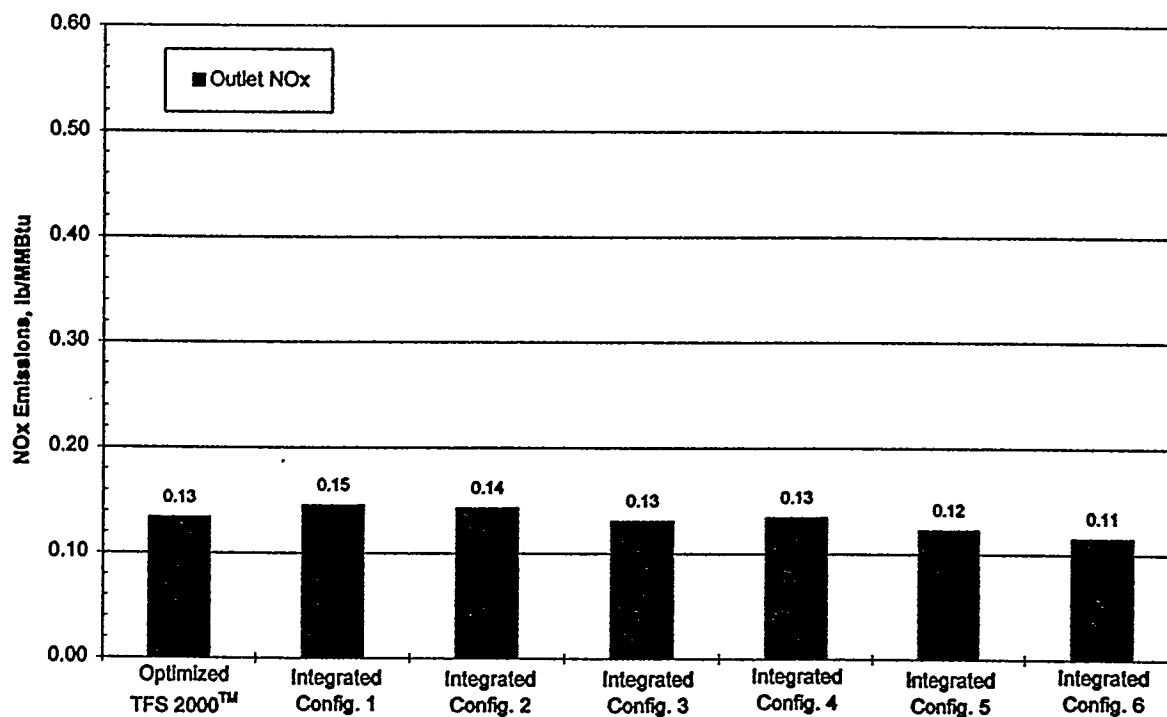


Figure 11-4 Effects of Integrated Staging on NOx

PLANS FOR NEXT QUARTER

Task 1

- Write paper for First Joint Power & Fuel Systems Contractors Conference.

Task 7

- Complete 200 acfm CeraNO_x test.

Task 8

- Complete evaluation of Hot SNOX vs. NID for the POCTF at RP&L.
- Complete preliminary designs of boiler, turbine/generator and heat exchangers and restart plant design.

Task 9

- Complete the test plan for the 5,000 acfm CeraNO_x test.

Task 10

- Complete reconfiguration of the test rig for the 5,000 acfm CeraNO_x test.

Task 11

- Initiate the 5,000 acfm CeraNO_x test.
- Draft Low-NO_x Firing System sections of the Subtasks 11.2 and 11.3 reports.

Task 12

- Initiate Phase II Draft Report.

APPENDIX A - 2 pages

U.S. DEPARTMENT OF ENERGY
MILESTONE SCHEDULE ☐ PLAN ☒ STATUS REPORT

Page 1 of 2
FORM APPROVED
OMB 1901-1400

DOE F1332.3 X
(11-84)

1. TITLE Engineering Development of Advanced Coal-Fired Low-Emission Boiler Systems - Phases II & III		2. REPORTING PERIOD October 1, 1994 - March 31, 1996		3. IDENTIFICATION NUMBER DE-AC22-92PC92159	
4. PARTICIPANT NAME AND ADDRESS Combustion Engineering, Inc. P.O. Box 500 Windsor, CT 06095-0500		5. START DATE October 1, 1994		6. COMPLETION DATE March 31, 1997	
7. ELEMENT CODE	8. REPORTING ELEMENT	9. DURATION	FY96		
		OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT	10. PERCENT COMPLETE a. Plan b. Actual		
1.0	PHASE II	▲	60 60		
7.0	Proj Mgt	▲	95 78		
8.0	Comp Dev	▲			
8.0	POCTF	▲			
8.1	Site Sel	▲	100 100		
8.2	Pre Dsn	▲	59 33		
9.0	Subsyst	▲			
9.1	Design	▲	100 100		
9.2	Plan	▲	100 95		
10.0	Constr	▲	100 95		
11.0	Subsyst	▲			
11.1	Oper	▲	62 62		
11.2	Test Ev	▲	42 35		
11.3	Dan Ev	▲	58 14		
12.0	Draft Report	▲	0 5		
11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE <i>John W. Regan</i> Apr. 5, 1996					

APPENDIX B - 11 pages

21ST COAL UTILIZATION &
FUEL SYSTEMS CONFERENCE

MARCH 1996

MAJOR IMPROVEMENTS IN PULVERIZED
COAL PLANT DESIGN

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ABSTRACT

The paper describes the work by the ABB team on the U.S. Department of Energy (DOE) project "Engineering Development of Advanced Coal-Fired Low-Emission Boiler Systems" (LEBS) which is part of the DOE's Combustion 2000 Program. The objectives of the LEBS Project are to dramatically improve environmental performance of future pulverized coal-fired power plants, to increase their efficiency and to reduce their cost of electricity using near-term technologies, i.e., advanced technologies that are partially developed. The overall objective is to expedite commercialization of the technologies that are developed under LEBS.

A major deliverable of the Project is the design of a large, in this case 400 MWe, commercial generating unit (CGU). The design being developed by the ABB team is projected to meet all the Project objectives, i.e., to reduce emissions of NO_x, SO₂ and particulates to one-third to one-sixth NSPS limits while increasing net station efficiency significantly and reducing the cost of electricity. With the use of a Kalina cycle the net plant efficiency will be 45% (HHV) or higher. This design and future work are described in the paper.

INTRODUCTION

The original LEBS emissions objectives have been gradually tightened and the efficiency objective gradually raised in response to pressure from industry and government. The contract objectives for emissions are now approximately one-half of the original values for NO_x, SO_x and particulates and the efficiency objective has been raised substantially - 38% to 42% (HHV, net). The ABB Team has raised the efficiency target another 3-4 percentage points.

LEBS is restricted to pulverized coal firing (PC) which is viewed by many as less glamorous than other coal-fired technologies such as IGCC and PFBC, most likely because of the misconception that PC with the Rankine steam cycle has neared its limits of efficiency and emissions performance. In truth, there is considerable room for cost-effective improvements. The required development effort is not great and the result will be low-risk low-cost familiar-looking systems which will be readily accepted by the conservative utility industry. The technologies described below are fuel-flexible and suited to retrofit, repowering and new applications.

IN-FURNACE NO_x CONTROL

General Description

The most cost effective way to reduce nitrogen oxides when burning a fossil fuel, coal in this case, is through an in-furnace NO_x reduction process. The foundation for the Team's in-furnace NO_x reduction process is TFS 2000™, a proven technology which is currently being employed on a commercial basis. Briefly, it involves substoichiometric fuel/air operation in the firing zone, the use of concentrically arranged air injection in the windbox whereby the air jets are aimed at a larger imaginary circle than the fuel jets, the use of separated over fire air and the use of a pulverizer with a dynamic classifier. As with all in-furnace NO_x reduction systems, the key is to be able to operate in a mode which produces low NO_x without exacerbating the combustible losses, notably the carbon content in the fly ash. The objective of this in-furnace NO_x reduction process is to reduce nitrogen oxides leaving the primary furnace to 0.1 lb NO_x/MM Btu (0.14 g/Nm³) or lower while maintaining an acceptable level of carbon in the fly ash.

The process for evaluating the various firing system concepts/configurations involves the use of computational modeling, small scale experimental testing in a Fundamental Scale Burner Facility (FSBF) and larger scale experimental testing in a Boiler Simulation Facility (BSF) (Figure 1). Additionally, it has involved concurrent characterization of coal pulverization in a pulverizer equipped with a dynamic classifier. As NO_x levels are pushed ever lower it is imperative that the fuel particle size distribution also be more tightly specified as a primary means of controlling combustible losses. The primary activities which will be addressed in this paper are results from testing in the FSBF and characterization of one of the LEBS coals in a Pulverizer Development Facility. Computational modeling will be addressed briefly.

Computational Modeling

Two models are employed to help analyze the various firing systems concepts that have been formulated. A kinetics reaction model, CHEMKIN, is used to provide a preliminary evaluation of the potential for various concepts to achieve the desired results. It is recognized that results from this evaluation are qualitative at best and can only be used to provide trends; nevertheless its use can be an important screening tool to help prioritize the most promising concepts for further evaluation. A computational fluid dynamics model, FLUENT, is used to further evaluate concepts under conditions which better simulate actual boiler operation. Unlike CHEMKIN which assumes either well-stirred reactor conditions or perfect plug flow conditions, FLUENT is able to simulate real-world mixing conditions. The BSF has been modeled with FLUENT. Experimental measurements from the BSF compare quite well with those predicted by FLUENT, namely parameters such as gas temperatures and gaseous concentrations such as O₂ and CO. Having validated FLUENT with BSF data, the intent was to use it as well as the CHEMKIN model in ways that capitalize on their respective strengths to evaluate and screen various firing system concepts.

Fundamental Scale Burner Facility (FSBF)

The Fundamental Scale Burner Facility (FSBF) is a horizontally fired cylindrical combustor which has a capacity of 5 million Btu/hr (Figure 2). It has been configured to simulate tangential firing; air and fuel are injected from four nozzles for each plane, or "elevation", the term used to describe a plane in a tangential firing system. There are a number of planes from which fuel or air can be injected to simulate and evaluate a particular firing arrangement. Additionally there are air-only injectors downstream of the main windbox to simulate over fire air injection.

Low NO_x firing generally requires that the main windbox or burner zone be fired under substoichiometric conditions. Table 1 shows the relative NO_x values as a function of bulk stoichiometry in the main windbox zone as simulated in the FSBF. Configuration 1 represents a

base case where all of the combustion air is injected through the main windbox; the NO_x level is arbitrarily shown as 100%. Configurations 2 and 3 show relative NO_x values for substoichiometric firing in the main windbox and with different amounts of separated over fire air (SOFA) in SOFA levels 1 and 2. As expected, substoichiometric operation results in lower NO_x and the strategy for staging the SOFA also makes a difference in the final NO_x levels.

Table 1. Relative NO_x Levels vs. Main Burner Zone Stoichiometry (MBZ) and Separated Over Fire Air (SOFA)

Configuration	NO_x %	MBZ Stoich	SOFA 1 Stoich	SOFA 2 Stoich
1	100	1.15	1.15	1.15
2	66	0.8	1.0	1.15
3	54	0.8	0.8	1.15

Initial testing in the FSBF was designed to evaluate a number of variables within the main firing zone, including firing system configuration and operating conditions, for their effect on NO_x . Table 2 shows results from a number of firing system configurations, some of which employ integrated firing system strategy. Relative to the base case, configurations 4 and 5 are run to produce lower NO_x without the use of SOFA, while configurations 6 and 7 show relative NO_x levels with the use of SOFA.

Table 2. Relative NO_x Levels for Integrated Firing Configurations vs. Base Case (Configuration 1)

Configuration	NO_x %	MBZ Stoich	SOFA 1 Stoich	SOFA 2 Stoich
1	100	1.15	1.15	1.15
4	64	1.15	1.15	1.15
5	59	1.15	1.15	1.15
6	54	0.8	0.8	1.15
7	49	0.8	0.8	1.15

Coal Pulverization

As noted above, specification and control of coal particle size distribution is an important prerequisite for successful operation of a low NO_x firing system. Conditions for achieving low NO_x tend to run counter to those that are favorable for good coal combustion; therein lies the challenge. Paying attention to the proper coal particle size distribution has the obvious effect of facilitating better carbon burnout and the perhaps not-so-obvious effect of enhancing NO_x reduction through earlier release of nitrogen species in the near-burner zone, where the opportunity for conversion to molecular nitrogen is increased.

A Pulverizer Development Facility (PDF) was constructed for the study and characterization of coal pulverization and classification. The PDF includes a coal storage and feed system and a fine coal collection system as necessary support equipment for the pulverizer itself. The pulverizer represents a commercial design, based on a size 323 pulverizer, but with the flexibility to change out important components within the mill, such as grinding elements and classifiers. The capacity of the PDF is 3.5 tons/hr.

The early focus of the LEBS-related work which utilizes the PDF has been to characterize the coal particle size distribution and mill power requirements. Ideally it is desired that the top size of the

coal particles be closely controlled and that classification is more efficiently carried out so that sufficiently fine particles are not needlessly recirculated back to the grinding zone. The use of a dynamic classifier is one way of accomplishing this.

Table 3 shows results from recent testing with various dynamic classifier designs as compared with a base case static classifier design. It is apparent that the goals of greater coal fineness, less coarse material and lower power requirements have all been achieved with at least two of the dynamic classifier designs. Results have been demonstrated with conventional air-coal ratios. Future firing tests in the FSBF will employ the use of coals having various particle size distributions to ascertain and quantify the benefits of using finer coal.

Table 3. Dynamic Classifier Characterization

	Static Classifier	Dynamic Classifier Designation			
		HP1	HP2	RB1	RB2
Product Size (wt %)					
+50 mesh	0.1	0.2	0.0	0.0	0.0
+100 mesh	2.4	1.2	0.6	0.5	0.6
-200 mesh	84.3	85.7	92.7	93.1	90.7
Relative Power Requirements (%)	100	81	98	97	107

STACK NO_x, SO₂ AND PARTICULATES

General Description of Control Technology

The ABB Team believes strongly that it is essential that a choice of technologies be available to designers to enable them to provide the optimum system for any given set of project conditions. This is particularly true in the area of flue gas cleaning because of the plethora of regulations and fuel characteristics. For the conditions established for the LEBS plant, the Team evaluated several viable technologies and selected a modified SNO_x™ process, referred to as the SNO_x™ Hot Process. The SNO_x™ process, which simultaneously removes nitrogen oxides and sulfur oxides from flue gases, is a licensed technology developed by Haldor/Topsøe A/S, Denmark. The SNO_x™ technology has been demonstrated in several forms, one as a Clean Coal Technology, and has been constructed and operated on a commercial scale in Denmark. The SNO_x™ technology consists of five key process areas: particulate collection, NO_x reduction, SO₂ oxidation, sulfuric acid condensation, and acid conditioning. For the LEBS design, the particulate collection and NO_x reduction process are integrated into a single process step.

Particulate/NO_x Control

The first step, particulate collection, will have a direct effect on the performance of the downstream SO₂ converter, particularly the frequency of cleaning the SO₂ catalyst. This is due to the inherent ability of the catalyst to retain greater than 90% of all particulate matter which enters the converter. The collection of this particulate matter, over time, will cause the gas draft loss to increase. The virgin draft loss can, however, be restored through catalyst cleaning, called screening. Higher dust loads at the SO₂ converter inlet require more frequent cleaning which causes higher catalyst attrition losses.

To achieve the required particulate loadings at the SO₂ converter inlet, a high efficiency collection device must be employed. For the LEBS design, a ceramic filter manufactured by CeraMem was

selected for testing. The construction of the ceramic filter is based on the use of porous honeycomb ceramic monoliths. These high surface area, low cost materials were developed for, and are widely used as, catalyst supports. The monoliths have many cells or passageways which extend from an inlet face to an opposing outlet face. Cell structure is usually square and cell density can vary from 25 to 1400 cells per square inch. Mean pore size can range from 4 to 50 microns.

The superior properties of commercially available monoliths make them ideally suited for applications requiring high thermal stability, mechanical strength, and corrosion resistance. These rigid ceramics have been used for years as NO_x SCR catalyst supports in combustion flue gas applications. The monolith structure used for catalyst support material is readily adapted to function as a particulate filter. The monolith structure is modified by plugging every other cell at the upstream face with a high-temperature inorganic cement. Cells which are open at the upstream face of the monolith are plugged at the downstream face. Flue gas is thereby constrained to flow through porous cell walls, and at appropriate intervals, the filter is cleaned by backpulse air.

CeraMem has developed the technology for applying thin ceramic membrane coatings to the monoliths and controlling the pore size. The thin (approximately 50 microns) membrane coating has a pore size approximately 100-fold finer than that of the monolith support. Thus the filter retention efficiency is determined by the membrane pore size, not the monolith pore size. The ceramic filter will operate as an absolute filter; that is, all particulate over a certain diameter will be removed from the gas stream. The split diameter is determined and controlled by the ceramic membrane.

In the LEBS design, commercially-tested SCR catalyst is applied to the clean side of the particulate filter. As with other low dust SCR applications, concerns about flyash poisoning of the catalyst are eliminated, and catalyst loadings may be reduced as the catalyst will have a "higher" activity. Also, in this application, the reaction kinetics will not be controlled by mass diffusion as in other monolith applications. Instead, the kinetics will be much faster, taking advantage of "forced diffusion", where the flue gas will come into forced contact with the catalyst as it passes through the monolith wall. A third benefit of this technology in relation to SCR performance will come about from elevated conversion temperature. Typical SCR applications operate at about 675°F, whereas the LEBS application will operate at a slightly higher temperature of 750-775°F. Increased temperature should not affect catalyst life, but should improve the efficiency of the reducing reagent, in this case ammonia. The increase in temperature should result in lower ammonia concentrations at the SCR outlet, often called "ammonia slip".

Taking advantage of the clean-side catalyst application, forced diffusion kinetics, and higher reduction temperature should give much higher NO_x reduction efficiencies and efficient reducing reagent consumption. Early data indicate that at NO_x inlet concentrations of 200 ppm, NO_x reduction could exceed 90% without any measurable ammonia slip.

In particulate collection tests, collection efficiency was found to be almost absolute. Outlet emissions could not be detected by standard EPA Method 5 techniques, and were determined by laser-light scattering instrumentation.

SO₂ Control

SO₂ emissions are controlled by the SO₂ oxidation catalyst, sulfuric acid condensers, and acid conditioning system. An oxidation catalyst, which is widely used in the sulfuric acid industry, converts the SO₂ to SO₃ at greater than 97% efficiency. The efficiency of the catalyst is not affected by the presence of water vapor or chlorides in concentrations up to 50% and several hundred ppm, respectively. An additional benefit of the sulfuric acid catalyst is its ability to oxidize carbon monoxide and hydrocarbons present in the flue gas stream to innocuous compounds.

The SO_3 in the gas leaving the SO_2 converter is hydrated and condensed in two steps. First, the bulk of the SO_3 is hydrated to sulfuric acid vapor as the flue gas passes through an air heater and the temperature drops to approximately 500°F. At this point, the flue gas is still well above the acid dewpoint, thus avoiding acid condensation and corrosion of the ductwork. The flue gas then enters the wet sulfuric acid (WSA) condenser, a unique tube and shell falling film condenser with the boiler combustion air used as the cooling medium on the shell side. Borosilicate glass tubes are used to convey and cool the flue gas. Both the hydration and the condensation reactions are exothermic, thereby adding heat to the flue gas and subsequently to the boiler thermal system. The design and operation of the WSA condenser make possible virtually complete condensation and capture of the sulfuric acid at concentrations of 92 to 95 wt %.

To this point, SNO_x ™ systems have not been built with SO_2 removal efficiencies of greater than 95%, and therefore, data other than that obtained at laboratory scale would not support the ability to achieve higher removal efficiencies. However, ultra-high removal efficiencies (typically greater than 98%) have been studied, with the information being used to design, build, and operate high-efficiency systems. As this is a catalytic system, SO_2 removal efficiency is fixed and somewhat inflexible. If a system is designed for a specific removal efficiency, it will maintain that degree of control over a wide operating range without any drop-off, unlike chemical reagent systems which tend to become gas-side limited and lose removal capability as inlet SO_2 levels decrease. Increasing removal efficiency would require minor modification of the converter vessel with catalyst addition.

SO_3 emissions will be controlled by the efficient condensation system, in excess of 99.9% condensation. However, some SO_3 will pass through the system and will exit the stack, and it is expected that this amount would not be in excess of 20 ppm - a level similar to emissions from present-day wet or dry desulfurization systems.

Improved Thermal Efficiency

Heat addition, transfer, and recovery are of significant importance in the SNO_x ™ process. The process generates recoverable heat in several ways. All of the reactions which take place with respect to NO_x and SO_2 removal are exothermic and increase the temperature of the flue gas. This heat is recovered in the air heater and WSA condenser for transfer to the combustion air. The WSA condenser lowers the temperature of the flue gas to about 210°F.

HIGH EFFICIENCY POWER CYCLES

Steam Cycle

The most widely used power plant cycle in the United States has been a subcritical single reheat cycle. It features a drum boiler operated to produce 2400 psig/1000°F at the turbine throttle. In the late 1950's, the industry introduced supercritical steam cycles which enabled higher plant efficiencies and improved operating costs. As the initial problems were resolved and supercritical technology matured, these plants demonstrated availabilities comparable to their subcritical counterparts. However, for a variety of reasons, but mainly due to the low cost of fuel, there have been no supercritical plants constructed in the United States since the late 1970's. The original incentives for supercritical cycle development are even more critical today. The time has come to take a hard look at cycle options and improvements in heat rate through higher steam conditions. Heat rate improvement means reduced cost per unit of electricity produced. For over a decade, the authors' company, with the support from DOE and EPRI, has been participating in the development of an advanced steam cycle with throttle conditions of 4500 psig/1100°/1100°/1100°F. This plant is commercially available and includes state-of-the-art technical advances made in materials, manufacturing processes, design analyses, and control systems. Plants with very similar steam conditions are in successful commercial service in Japan and Denmark (where high efficiency has greater value.) Depending on the condenser pressure, plant capacity, and type of coal-fired, the net plant HHV efficiency is approximately 41% to 43%. Although the steam conditions may

appear to be advanced, they do not constitute a significant departure from the current experience. One may only need to recall a unit which was commissioned in 1959. With initial steam conditions of 5000 psig, 1200°F and two reheats of 1050°F, this unit had the highest steam conditions and efficiency of any plant in the world. Due to some initial problems, very few of which were related to high temperature and pressure, the steam turbine throttle conditions were reduced to 4700 psig and 1130°F. It remains an important unit in the owner's future generation plan as evidenced by life extension beyond the year of 2010. However, in contrast to that unit which was designed for base load capacity needs, a state-of-the-art plant would be capable of sliding pressure mode of operation and cycling duty with fast start-up and fast load change rates. These desired plant characteristics are accommodated by introducing a steam generator with spirally wound furnace walls, an integrated start-up system, and a split back pass for steam temperature control. Past experiences are factored into the design of critical components. Major design improvements include improved materials, *e.g.*, advanced ferritic alloys such as T91 (9Cr) and modified 12 Cr for piping, headers, and steam turbine rotors. Better analysis techniques combined with advanced monitoring and control systems ensure that the state-of-the-art plant would be able to operate without any loss of material or component life over and above that expected from current units.

Higher steam conditions, such as 5000 psig/1200°/1200°/1200°F, offer the prospect of an additional plant efficiency improvement of approximately 3%. The estimated net plant efficiency is in the range of approximately 42% to 44%. Design of the high temperature components is not expected to change significantly from the state-of-the-art plant except for some material upgrade in the critical areas. For base load capacity, technology is probably available to build this plant today, particularly, if the reheat temperatures are reduced to 1150° or 1100°F. For cycling duty, the key to success lies in the application of advanced high strength ferritic and austenitic alloys developed in the past decade for such critical components as furnace wall tubing, headers, piping, and steam turbine rotors. It is believed that with some additional R&D effort the 5000 psig steam cycle can be offered commercially in the 2000 to 2002 time frame.

Significant additional thermodynamic gain can be achieved by adopting even higher steam conditions such as 6000 psig/1300°/1300°/1100°F. The expected net plant efficiency should be in the range of 43.5% to 45.5%. Since these steam conditions fall outside the realm of the current experience, there is little doubt that formidable technical problems will need to be solved. To meet the future needs for high efficiency, the industry is beginning to experiment with high steam temperature applications. Conceptual designs and preliminary test results at steam conditions of 1500 psig/1500° F have been reported in the literature. To facilitate implementation of the new technology consistent with the needs of the early 21st century, perhaps the time has come for comprehensive assessment of the ultra high steam conditions.

Kalina Cycle

An alternative approach to the use of higher temperatures and pressures to gain plant efficiency is to change the cycle working fluid. The use of mixtures as the working fluid provides the ability to vary the composition throughout the cycle. This provides a structural advantage in designing a power plant cycle by providing freedom to minimize thermodynamic losses throughout the process. The Kalina cycle, currently under demonstration, is one such cycle.

In the Kalina cycle a mixture of ammonia and water is used as the working fluid. In contrast to a single component, the temperature of the ammonia/water working fluid continually changes during the boiling process. The light component (ammonia) boils off first, leaving behind a mixture with a greater concentration of the heavier component (water). As this occurs, the boiling temperature of the remaining liquid increases. This fundamental degree of freedom facilitates the minimization of thermodynamic losses.

For direct fired Kalina cycle applications (those where the source of thermal energy input to the cycle comes from fuel combustion) net plant efficiencies in the range of 45% to 50% (HHV) are possible

today. This range can be achieved at vapor conditions of 2400 psig/1050°F/1050°F/1050°F. Similar to the steam Rankine cycle, increasing vapor temperatures will augment the efficiency advantage of Kalina cycles.

Kalina cycle plants can take advantage of all LEBS technological advances in combustion and emissions control. The plant cycle may be structured to accommodate the application of the SNO_xTM Hot Process, offering efficiency improvement versus the conventional Rankine cycle. Finally, because the efficiency gains are a result of structural improvements in the plant cycle, the capital cost of the plant may be less than a conventional Rankine subcritical single reheat plant.

COMMERCIAL GENERATING UNIT DESIGN

The LEBS 400 MWe Commercial Generating Unit (CGU) is illustrated in Figure 3. Technologies have been selected to achieve greatly reduced levels of emissions, increased thermal efficiency, reduced waste and improved costs. These technologies are an advanced low-NO_x combustion system, the SNO_xTM Hot Process, and a Kalina boiler and turbine cycle.

This combination of emission control processes meets or betters all of the target emission levels for the LEBS Project, while producing either benign or saleable by-products from the gas treatment. The Kalina cycle and the SNO_xTM Hot Process enable the design to meet the efficiency objective and, indirectly, the cost of electricity objective. Expected performance of the CGU compared to an NSPS-compliant plant is listed in Table 4. The NSPS plant assumes a 2400 psi/1000°/1000° cycle with wet limestone FGD and an electrostatic precipitator.

Table 4. 400 MWe CGU

		NSPS PLANT	LEBS CGU
SO ₂	lb/mm Btu*	0.6	0.1
NO _x	lb/mm Btu	0.6	0.1
Particulate,	lb/mm Btu*	0.03	0.01
Net Efficiency (HHV),	%	35.4	45

*3 lb S and 15.4 Lb ash per million Btu in the coal.

• • • • •

REFERENCES

1. Regan, J. W., et al, 1995, "Improving Pulverized Coal Plant Performance", presented at the International Joint Power Generation Conference, Minneapolis, MN.

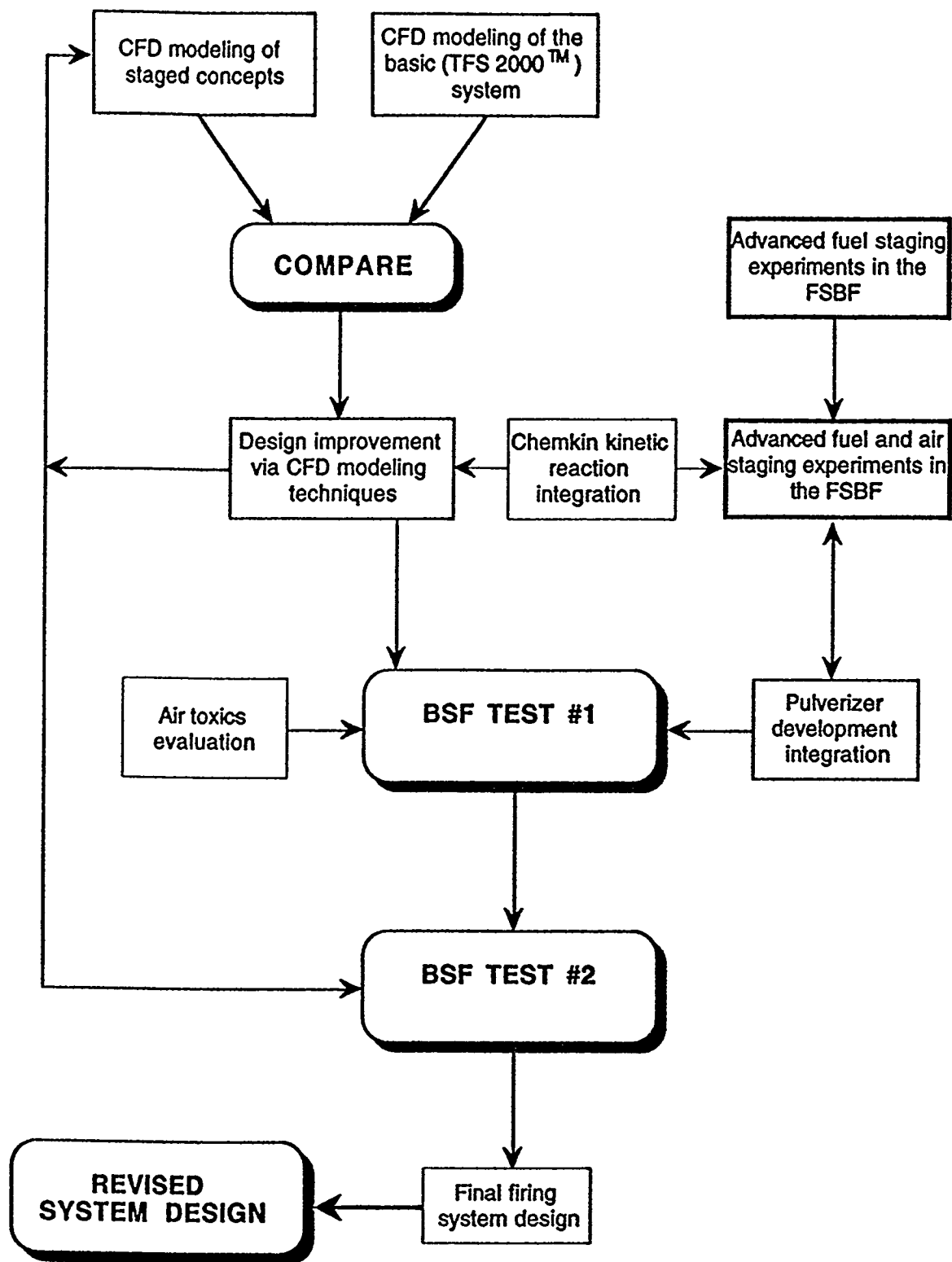


Figure 1 - LEBS Work Flow Chart

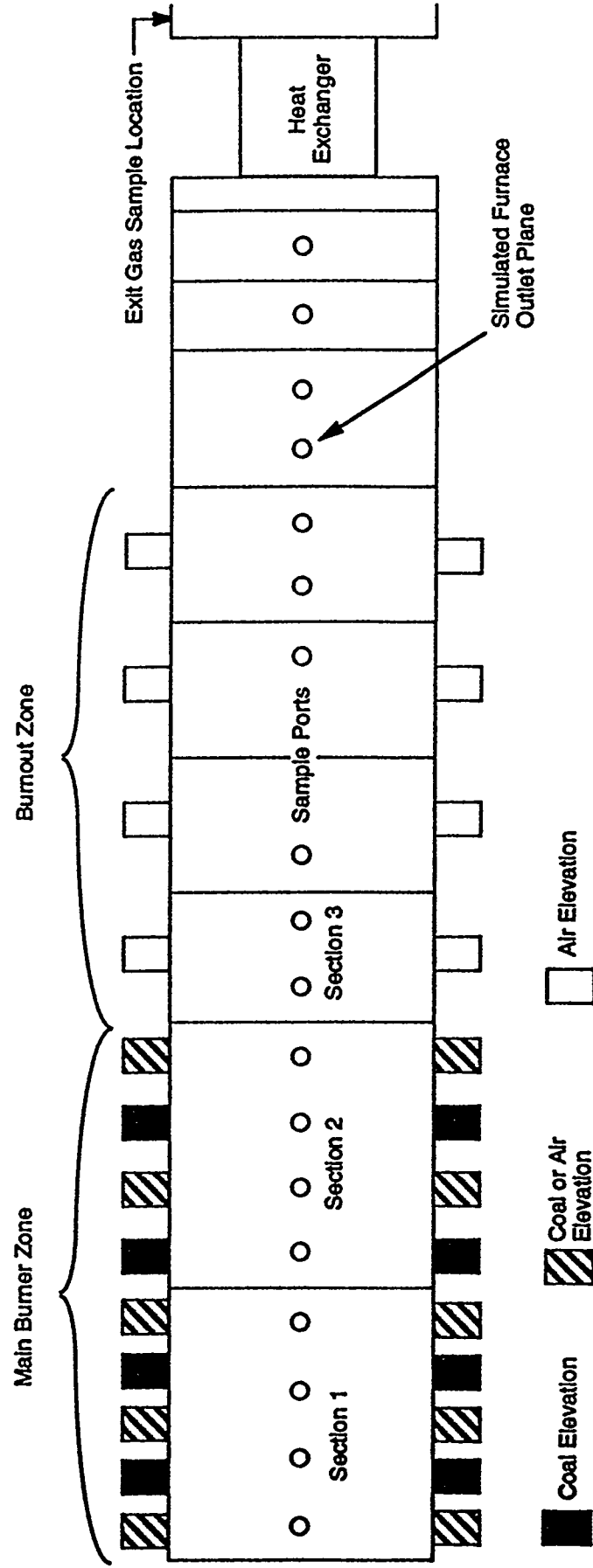


Figure 2 - Schematic of Fundamental Scale Burner Facility

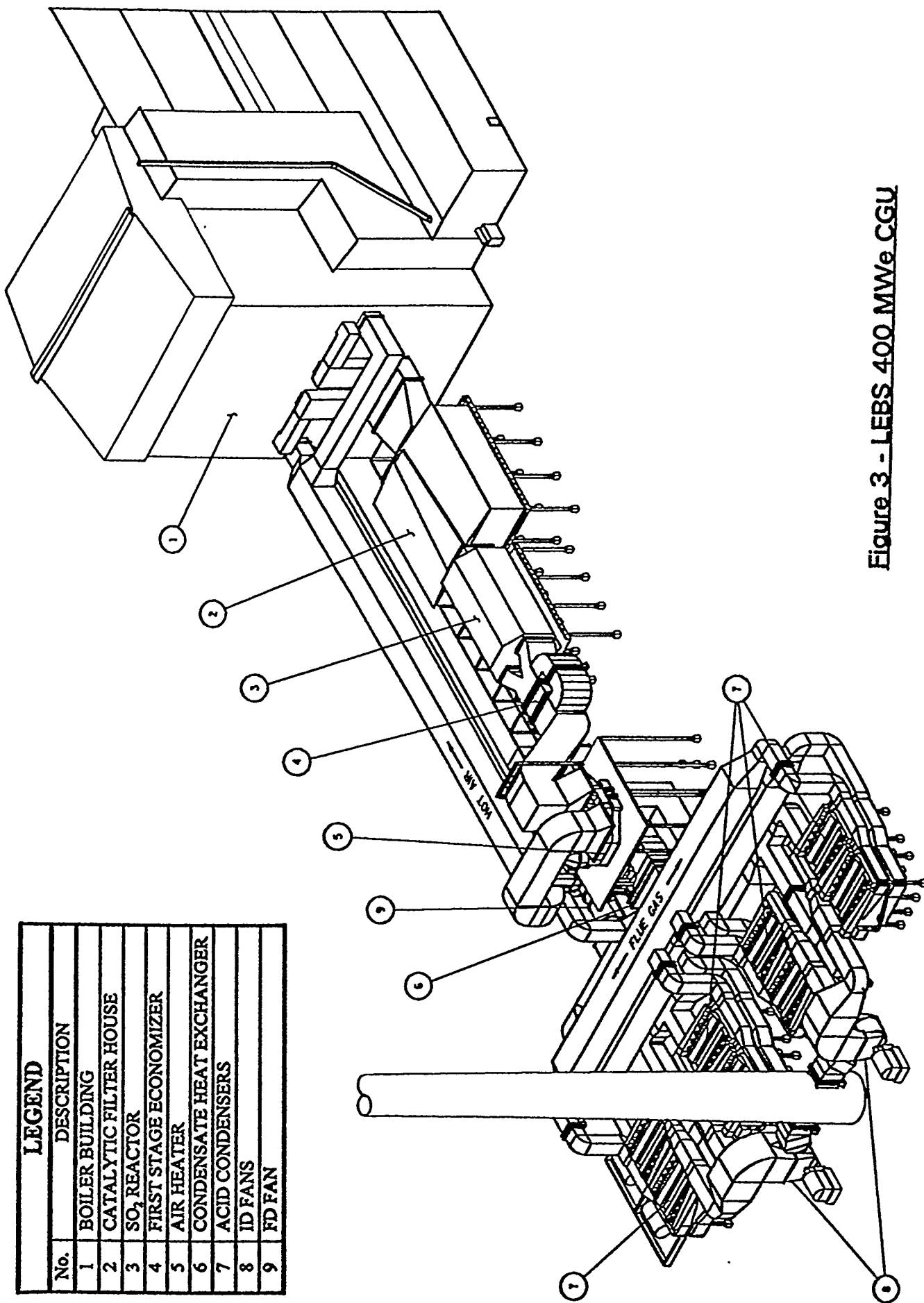


Figure 3 - LFBs 400 MWc CGU

LEGEND	
No.	DESCRIPTION
1	BOILER BUILDING
2	CATALYTIC FILTER HOUSE
3	SO ₂ REACTOR
4	FIRST STAGE ECONOMIZER
5	AIR HEATER
6	CONDENSATE HEAT EXCHANGER
7	ACID CONDENSERS
8	ID FANS
9	FD FAN